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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of Charles J. Stouffer and David C. Bugby

Serial No.: Not yet assigned Group Art Unit:

Filed: Herewith Examiner:

For: HIGH TEMPERATURE ISOSTATIC PRESSURE BONDING OF HOLLOW  
BERYLLIUM PRESSURE VESSELS USING A BONDING FLANGE

Assistant Commissioner for Patents  
Box PATENT APPLICATION  
Washington, D.C. 20231

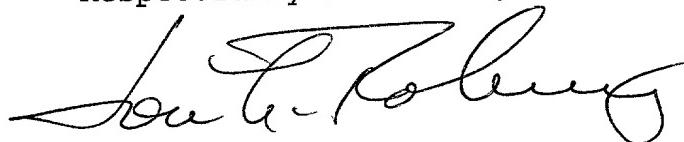
Dear Sir:

Enclosed please find the following:

1. Specification, abstract and claims (4 independent, 17 dependent, 21 total) (17 pages);
2. Informal drawings (6 figures, 6 sheets);
3. Declaration and Power of Attorney;
4. Assignment with Recordation Sheet;
5. Verified Statement Claiming Small Entity Status - Independent Inventor;
6. Verified Statement Claiming Small Entity Status - Small Business Concern;
7. One check in the amount of \$468.00 (\$380.00 for filing application, \$40.00 for filing assignment document, \$39.00 for excess independent claim and \$9.00 for excess claims); and,
8. Certificate of Express mailing.

The Commissioner is hereby authorized to charge any fee deficiency, or credit any overpayment, to Deposit Account No. 18-1579. The Commissioner is also authorized to charge Deposit Account No. 18-1579 for any future fees connected in any way to this application. Two copies of this letter are enclosed.

Respectfully submitted,



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**VERIFIED STATEMENT CLAIMING SMALL ENTITY STATUS  
(37 CFR 1.9(f) & 1.27(b))—INDEPENDENT INVENTOR**

Docket Number (Optional)

C. DCB

Applicant or Patentee: Charles J. Stouffer and David BugbySerial or Patent No.: Not Yet IssuedFiled or Issued: HerewithTitle: High Temperature Isostatic Pressure Bonding of Hollow Beryllium Pressure Vessels Using a Bonding Flange

As a below named inventor, I hereby declare that I qualify as an independent inventor as defined in 37 CFR 1.9(c) for purposes of paying reduced fees to the Patent and Trademark Office described in:

- the specification filed herewith with title as listed above.
- the application identified above.
- the patent identified above.

I have not assigned, granted, conveyed or licensed and am under no obligation under convey or law to assign, grant, convey or license, any rights in the invention to any person who would not qualify as an independent inventor under 37 CFR 1.9(c) if that had made the invention, or to any concern which would not qualify as a business concern under 37 CFR 1.9(d) or a nonprofit organization under 37 CFR 1.9(c).

Each person, concern or organization to which I have assigned, granted, conveyed, or licensed or am under an obligation under contract or law to assign, grant, convey, or license any rights in the invention is listed below:

- No such person, concern, or organization exists.
- Each such person, concern or organization is listed below.

**SWALES AEROSPACE, INC.**

Separate verified statements are required from each named person, concern or organization having rights to the invention averring to their status as small entities. (37 CFR 1.27)

I acknowledge the duty to file in this application or patent, notification of any change in status resulting in loss of entitlement to small entity status prior to paying, or at the time of paying, the earliest of the issue fee or any maintenance fee due after the date on which status as a small entity is no longer appropriate.(37 CFR 128(b))

I hereby declare that all statements made herein of my own knowledge are true and that all statements made an information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application, any patent issuing thereon, or any patent to which this verified statement is directed.

Charles J. Stouffer

NAME OF INVENTOR

Signature of inventor

11/1/99

Date

David Bugby

NAME OF INVENTOR

Signature of inventor

11/1/99

Date

NAME OF INVENTOR

Signature of inventor

Date

**VERIFIED STATEMENT CLAIMING SMALL ENTITY STATUS  
(37 CFR 1.9(f) & 1.27(c))—SMALL BUSINESS CONCERN**

Docket Number (Optional)

Applicant or Patentee: Charles J. Stouffer and David Bugby DB  
 Serial or Patent No.: Not Yet Issued  
 Filed or Issued: Herewith  
 Title: High Temperature Isostatic Pressure Bonding of Hollow Beryllium Pressure Vessels Using a Bonding Flange

I hereby declare that I am

- the owner of the small business concern identified below.  
 an official of the small business concern empowered to act on behalf of the concern identified below:

NAME OF SMALL BUSINESS CONCERN Swales Aerospace, Inc.

ADDRESS OF SMALL BUSINESS CONCERN 5050 Powder Mill Road, Beltsville, MD 20705

I hereby declare that the above identified small business concern qualifies as a small business concern as defined in 13 CFR 121.12, and reproduced in 37 CFR 1.9(d), for purposes of paying reduced fees to the United States Patent and Trademark Office, in that the number of employees of the concern, including those of its affiliates, does not exceed 500 persons. For purposes of this statement, (1) the number of employees of the business concern is the average over the previous fiscal year of the concern of the persons employed on a full-time, part-time or temporary basis during each of the pay periods of the fiscal year, and (2) concerns are affiliates of each other when either, directly or indirectly, one concern controls or has the power to control the other, or a third party or parties controls or has the power to control both.

I hereby declare that rights under contract or law have been conveyed to and remain with the small business concern identified above with regard to the invention described in:

- the specification filed herewith with title as listed above.  
 the application identified above.  
 the patent identified above.

If the rights held by the above identified small business concern are not exclusive, each individual, concern or organization having rights in the invention must file separate verified statements averring to their status as small entities, and no rights to the invention are held by any person, other than the inventor, who would not qualify as an independent inventor under 37 CFR 1.9(c) if that person made the invention, or by any concern which would not qualify as a small business concern under 37 CFR 1.9(d), or a nonprofit organization under 37 CFR 1.9(e).

Each person, concern, or organization having any rights in the invention is listed below:

- no such person, concern or organization exists.  
 each such person, concern or organization is listed below.

Separate verified statements are required from each named person, concern or organization having rights to the invention averring to their status as small entities. (37 CFR 1.27).

I acknowledge the duty to file, in this application or patent, notification of any change in status resulting in loss of entitlements to small entity status prior to paying, or at the time of paying, the earliest of the issue fee or any maintenance fee due after the date on which status as a small entity is no longer appropriate (37 CFR 1.289(b)).

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application, any patent issuing thereon, or any patent to which this verified statement is directed.

NAME OF PERSON SIGNING Thomas L. Wilson, Sr.

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SIGNATURE Thomas L. Wilson DATE 11-01-99

CERTIFICATE OF EXPRESS MAILING

Express Mail Mailing Label Number EL449837974US

Date of Deposit: November 4, 1999

I hereby certify that the patent application of Charles J. Stouffer and David C. Bugby for a **HIGH TEMPERATURE ISOSTATIC PRESSURE BONDING OF HOLLOW BERYLLIUM PRESSURE VESSELS USING A BONDING FLANGE** including the specification, abstract, and claims (4 independent, 17 dependent, 21 total) (17 pages); informal drawings (6 figures, 6 sheets); declaration and power of attorney; an assignment together with a recordation cover sheet; Verified Statement Claiming Small Entity Status - Small Business Concern; Verified Statement Claiming Small Entity status - Independent Inventor; and a check in the amount of \$468.00 (\$380.00 for filing application, \$40.00 for filing assignment document, \$39.00 for excess independent claim and \$9.00 for excess claims), are being deposited with the United States Postal Service for "Express Mail" service under 37 C.F.R. § 1.10 on the date indicated above and are addressed to the Assistant Commissioner for Patents, Box Patent Application, Washington, D.C. 20231.



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1      **Title:**     **HIGH TEMPERATURE ISOSTATIC PRESSURE BONDING OF**  
2                   **HOLLOW BERYLLIUM PRESSURE VESSELS USING A**  
3                   **BONDING FLANGE**

4      **Inventor:**   Charles J. Stouffer and David C. Bugby

5                   **BACKGROUND OF THE INVENTION**

6      **1. Field of the Invention**

7                  The present invention relates generally to methods of bonding and sealing together metal  
8                  parts. In particular, the present invention relates to processes of fabricating and repairing hollow  
9                  beryllium structures, that must be leak tight and that experience temperature cycles, through high  
10                 temperature isostatic pressure bonding.

11                **2. Background Information**

12                Typically beryllium vessels have been formed by welding or brazing using a filler metal,  
13                such as aluminum or silver. The problem with such vessels is that the coefficient of thermal  
14                expansion (CTE) of the filler metal is substantially different from that of the bulk beryllium. The  
15                use of a filler metal for joining results in low strength properties. Although these methods can be  
16                adequate under some circumstances for systems that require lower strength properties and do not  
17                go through temperature cycling, they will not guarantee leak tightness, particularly with large or  
18                complex beryllium containers.

19                Furthermore, these bonding methods should not be used with pressure vessels having  
20                high internal pressures and that are subjected to large temperature variations,  $\Delta T$ . One example  
21                of such a vessel is a space flight Cryogenic Thermal Storage Unit (TSU). Cryogenic TSUs  
22                experience a large temperature swing ( $\Delta T \approx 300$  K), and require large factors of safety in the  
23                bond area to meet the aerospace requirements.

1           A need therefore exists for improved bonding methods that provide the necessary  
2           reliability.

3           **SUMMARY OF THE INVENTION**

4           It is therefore an object of the present invention to provide a means for building or  
5           repairing fabricated structures that have high strength joints.

6           It is therefore an object of the present invention to provide a means for building or  
7           repairing, without introducing a filler metal, hollow metal (e.g., beryllium) structures that meets  
8           high strength, temperature cycling applications, such as aerospace requirements.

9           It is therefore an object of the present invention to provide hollow metal (e.g., beryllium)  
10           pressure vessel structures that provide a bond joint homogeneous with the parent metal.

11           It is a further object of the present invention to provide a hot isostatic pressure (HIP)  
12           bond method of sealing outer shells regardless of size and configuration.

13           It is a further object of the present invention to provide a HIP bond method of sealing  
14           outer shells, with an external bond joint configuration.

15           It is proposed that the bonding method of the present invention can be used to seal  
16           pressure vessels, such as thermal storage devices for space flight applications, as well as other  
17           applications where reliability, low mass, and homogeneous properties to handle high strength  
18           with extreme temperature swings are important considerations. Typically these systems require  
19           weight optimization, high reliability and the ability to withstand large temperature cycling  
20           throughout their functional life. The HIP bond method of sealing a pair of outer shells is ideal  
21           for these applications, providing a vessel with a homogeneous material composition. An  
22           important aspect of the invention is to provide a reliable bond joint regardless of the size or  
23           configuration of the vessel being formed.

1 Some of the above objects are obtained by a method of bonding metal shells to form a  
2 vessel having an interior void. The method involves forming each of the metal shells with a  
3 peripheral flange and then aligning the metal shells with one another such that their respective  
4 peripheral flanges are engaged with one another. The aligned metal shells are assembled  
5 together with tooling to engage the flanges. Compression force is then applied to the flanges, via  
6 the tooling, at an elevated temperature so as to form a diffusion bond joint where the flanges  
7 meet.

8 Other of the above objects are obtained by a metal bond joint for use with hollow articles  
9 formed from metal shells. The bond joint includes a pair of opposed flanges and a diffusion  
10 bond. The pair of opposed flanges are in contact with one another, and each of the opposed  
11 flanges is disposed at the periphery of one of the metal shells. The flanges are aligned with one  
12 another and define a bond region where they are in contact with one another. The diffusion bond  
13 is formed between the pair of opposed flanges, across the entire bond region.

14 Still other of the above objects are obtained by a hollow metal article formed of a pair of  
15 opposed metal shells and a metal bond joint. The bond joint includes a pair of opposed flanges  
16 and a diffusion bond. The pair of opposed flanges are in contact with one another, and each of  
17 the opposed flanges is disposed at the periphery of one of the metal shells. The flanges are  
18 aligned with one another and define a bond region where they are in contact with one another.  
19 The diffusion bond is formed between the pair of opposed flanges, across the entire bond region.

20 More specifically, bonding of beryllium shells to form a beryllium vessel with an interior  
21 void (HIPV) is a process that has four interrelated steps: (1) preparation of beryllium shells (or  
22 blanks); (2) tooling fabrication and assembly of tooling with beryllium shells; (3) bonding at  
23 high temperature and pressure (i.e., the HIP process); and (4) machining of the vessel exterior.

Each of these steps is further defined below. Co-designing of the tooling (in the second step) and the peripheral flange (in the first step) interrelates these two phases of the bonding process. The result is a standardized way of creating bond joints.

## **BRIEF DESCRIPTION OF THE DRAWINGS**

The invention will be appreciated by review of the following detailed description, in conjunction with viewing of the appended drawing figures.

**Fig. 1** illustrates an exploded view of two HIP vessel blanks to be assembled together with tooling pins.

**Fig. 1A** illustrates a cross-sectional view of an article to be bonded in combination with a tooling assembly according to a preferred embodiment.

**Fig. 2** illustrates a cross-sectional view of a tooling assembly according to an alternate embodiment of the present invention, with an article to be bonded shown in phantom.

**Fig. 3** illustrates a detail view of the bond joint configuration of the article of Fig. 1A.

**Fig. 4** illustrates a HIP vessel manufacturing process.

**Fig. 5** illustrates a partial cross-sectional view of a tool assembly enclosed in a sealed can and ready for HIP.

## **DESCRIPTION OF THE PREFERRED EMBODIMENTS**

Diffusion bonding is a bonding process by which two work pieces (each formed of the same metal) are joined to one another without using a filler metal and without either of the work pieces melting. Each of the pieces to be bonded has a nominally flat surface. These two flat surfaces are butted up against one another and then a compressive force is applied to the pieces while the temperature is maintained at an elevated temperature that is below the melting point of the metal which the work pieces are made of.

1       The physical process that occurs at the interface between the two abutted surfaces of the  
2       work pieces is a diffusion process. Technically, no melting occurs since there is no wholesale  
3       dissociation of the atomic bonds in the bulk of the work pieces. At the surface interface,  
4       however, the atomic bonds do shift about substantially so that the two surfaces may integrate  
5       together as a homogeneous bulk with no gap. When the temperature is lowered and the  
6       compression forces relieved, the atomic lattice is stable and essentially homogeneous.

7           Typically, though, a number of small voids remain in the bulk as remnants of the surface  
8       interface gap that had previously existed. By selection of the appropriate surface texture (neither  
9       polished, nor overly rough) the number and size of these small remnant voids is minimized.  
10          Such optimized surface preparation know-how is well known in the art.

11          According to the present invention, special tooling is used to direct the compression force  
12       so that hollow beryllium articles can be formed effectively and reliably without crushing the  
13       article in the process. This is a very real concern since the hollow article can easily be crushed at  
14       the temperature and pressure combination at which diffusion bonding needs to be done. When  
15       diffusion bonding can be used successfully, a hollow beryllium article can be formed without a  
16       seam of filler metal.

17          Referring to **Fig. 1**, an exploded view is shown of two HIP vessel blanks **110, 120** to be  
18       assembled together with tooling pins **105**. A plurality of alignment holes **112** are drilled into the  
19       lower blank **120**. Likewise, a plurality of alignment holes (not shown) are drilled into the upper  
20       blank **110**. None of the alignment holes are drilled through their respective blanks. The tooling  
21       pins **105** fit into the alignment holes in each of the blanks **110, 120**.

1 An interior cavity **126** is formed in vessel blank **120**, and a corresponding interior cavity  
2 (not shown) is formed in vessel blank **110**. Processes for forming these interior cavities are  
3 discussed in detail below.

4 Referring to **Fig. 1A**, a cross-sectional view is shown of an article to be bonded in  
5 combination with a tooling assembly. The upper vessel blank **110** is mated to the lower vessel  
6 blank **120** so that the upper flange **110'** and the lower flange **120'** meet to form bonding flange  
7 **212**. A void **160** is formed between the two blanks **110, 120**. The upper tooling member **130**  
8 bears down on the top of flange **110'** and the lower tooling member **140** bears directly on the  
9 bottom of flange **120'**. No pressure is brought to bear on the walls of the blanks **110, 120** of the  
10 article, only the flanges. The large black arrows at the top and bottom of Fig. 1A indicate the  
11 directions in which opposing compression forces are to be applied in the HIP process.

12 The height H of the article formed by the joined blanks **110, 120** may be any size. This  
13 method is particularly advantageous for articles where the height H of the article exceeds two  
14 inches.

15 Referring to **Fig. 2**, a cross-sectional view is shown of a tooling assembly according to an  
16 alternate embodiment of the present invention, with an article **210** to be bonded shown in  
17 phantom. The tooling used in the HIP process controls the direction of compression and limits  
18 the amount of compression of the subject parts during bonding. The tooling must be fabricated  
19 to have the appropriate physical dimensions for the particular article being worked on. In the  
20 example shown in Fig. 2, bonding compression of the article **210** (i.e., blanks **110, 120**  
21 assembled according to the exploded view in Fig. 1) is constrained to only one direction. The  
22 blanks **110, 120** have respective flanges **110', 120'**, which when placed together form the  
23 bonding flange **212** of the article.

1       A peripheral retention member **270** around the periphery of the article **210** prevents any  
2       compression/bonding from occurring in the horizontal direction. A small gap between the article  
3       and the surrounding peripheral retention member **270** is implemented to insure that no  
4       contact/bonding occurs in the horizontal direction. The top tooling member **230** and the bottom  
5       tooling member **240** each have respective flanges **232**, **242**. The tooling members **230**, **240** are  
6       designed to contact the article **210** only on the top and bottom of the bonding flange **212** portion.  
7       The top flange **232** on the top tooling member **230** is machined down **408** (see Fig. 4) to regulate  
8       the amount of compression upon the bonding flange **212** of the article **210**. The compression  
9       stops when the top flange **232** of the top tooling member **230** comes in contact with the top of the  
10      peripheral retention member **270**. A typical compression gap, G, is 0.020-0.040 inches,  
11      depending upon the physical dimensions of the bonding flange **212**. The large black arrows at  
12      the top and bottom of Fig. 2 indicate the directions in which opposing compression forces are to  
13      be applied in the HIP process.

14       Referring to **Fig. 3**, a detail view of the bonding flange of the article of **Fig. 1A** is shown.  
15       The flange **110'** of the upper blank **110** and the flange **120'** of the lower blank **120**, when placed  
16      together, form the bonding flange **212** of the article. The thickness F of the bonding flange **212**  
17      is the combined thicknesses of the upper flange **110'** and lower flange **120'**. Although the HIP  
18      process may operate effectively where  $F > 2$  inches, it is preferred to practice the invention with  
19       $F < 2$  inches. The further away the pressure is applied from the bond line the more the energy is  
20      dissipated in the body, thereby reducing the actual pressure at the bond line. This is a substantial  
21      effect for purposes of determining the actual pressure applied at the bond line. After bonding,  
22      the bonding flange **212** will have a thickness  $F' = F - \Delta$ , where  $\Delta$  represents the amount of  
23      compression of the flange that is permitted during the HIP process.

1       The interior gap **170** shown in **Fig. 3** is not to scale and is, in fact, exaggerated to  
2       illustrate that the blanks **110**, **120** are shaped so that the bonding is intended to occur at the  
3       interface of the flanges **110'**, **120'**, in the area where force is applied, not where the walls of the  
4       blanks may abut. The large black arrows at the top and bottom of the flanges in **Fig. 3** indicate  
5       the directions in which opposing compression forces are to be applied, and where (on the  
6       flanges) they are to be applied in the HIP process. The interior gap **170** is formed by a pair of  
7       opposed depressions **172**, **174** that are formed in the blanks before they are assembled together  
8       with the tooling pins. The advantage of the interior gap **170** is that it eliminates pseudo cracks  
9       adjacent the bond joint. Without the interior gap **170**, the portion of the vessel where the walls  
10      abut, interior of the flange may not form a consistent diffusion bond. An incomplete diffusion  
11      bonding is a thin fissures that is, in effect a crack, (or pseudo crack). The presence of the pseudo  
12      cracks adjacent the bond joint would predispose the joint to be less reliable. That is because  
13      large positive internal pressures in the vessel tend to cause a pseudo crack to propagate through  
14      the bond joint, just as a fatigue crack would, leading to a structural failure of the vessel. The  
15      interior gap **170** avoids this danger by preventing any pseudo cracks from forming. A solid bond  
16      joint is formed, directly between areas where force is applied to the bonding flange, from the  
17      exterior of the vessel all the way to the interior of the vessel.

18       The steps illustrated in **Fig. 4** summarize the HIP vessel manufacturing process according  
19       to a preferred embodiment. The HIP vessel manufacturing process comprises four interrelated  
20       steps: (1) preparation of beryllium blanks (or shells); (2) tooling fabrication and assembly of  
21       tooling with beryllium blanks; (3) diffusion bonding at high temperature and pressure (i.e., the  
22       HIP process); and (4) machining of the vessel exterior. Each of these steps is further described  
23       as follows.

1           **Preparation of Beryllium Blanks**

2           A plurality of blanks is fabricated. Each of the blanks has an interior cavity that will  
3           yield the required final interior void when the blank is bonded to a mating blank. Starting with  
4           Be material **401**, the interior cavity geometry is machined **403** into the block. The external bond  
5           joint shown in Fig. 3 is also machined around the exterior of both blanks. Optionally, a portion  
6           of the exterior shell geometry is machined at this time.

7           Factors to be considered in dimensioning the interior geometry of the blank include the  
8           dimensions of the final article and the amount of compression that will be obtained during the  
9           bonding process. The preferred method for precisely machining the void volume is to drill a  
10          plurality of holes into the blanks **110**, **120** to form an interior cavity **126** into the blank. This is  
11          illustrated in the exploded view of Fig. 1. None of the holes are drilled through their respective  
12          blanks.

13          Besides mechanical machining (drilling, milling, etc.), alternate embodiments of the  
14          method according to the invention form the internal cavity in the blank by extrusion, by electrical  
15          discharge machining (i.e., “EDM”), or by etching. One particular form of etching that may  
16          advantageously be used is to form a beryllium “foam” by placing small solid copper spheres in  
17          molten beryllium, cooling the beryllium to solid form, and then etching the copper spheres out of  
18          the beryllium to leave behind many small spherical voids.

19           **Fabrication and Assembly of Tooling**

20          After the blanks **110**, **120** have been fabricated, they are assembled (refer to Fig. 1) with  
21          tooling pins **105** to aid in the alignment throughout the HIP process. Fig. 1A illustrates an  
22          alternate embodiment wherein at least one pillar **150** is placed in the void **160** formed by the  
23          internal cavities of the blanks. Although the pillar **150** is not required for the practice of the HIP

1 method according to the present invention, it is useful for ensuring that the article does not  
2 collapse during the HIP process. The tooling is assembled around the article such that the  
3 compression from the external pressure will only be applied at the location identified by the  
4 arrows in Fig. 3. All other locations will have a small gap to ensure no indirect pressure is  
5 induced into the article in the wrong direction.

6 For beryllium outer shells, the material used for fabricating 407 the tooling (130, 140,  
7 230, 240, 270) must show sufficient strength at 1700° F to withstand the 2000-psi pressure  
8 without deforming, so as to protect the article from inadvertent over-compression. Examples of  
9 suitable tooling materials are Inconel 718, IN 100, and molybdenum, due to their ability to  
10 maintain strength at high temperatures. Generally, materials that can maintain strength at high  
11 temperatures are applicable.

12 Before the article is completely assembled with the tooling structures, the baseline  
13 positions of the exterior and interior features of the article are registered 405. This registration of  
14 positions is done using x-rays and scribe indexing.

15 As a final step of the tooling process, the tooled article is placed in a seal welded (usually  
16 steel) can. Refer to **Fig. 5**. The assembled combination of the article with the tooling (230, 240,  
17 270) is enclosed in a can having a bottom 503 welded 505 to a side 501, which is welded 502 to  
18 a top 504.

## 19 **The HIP Process**

20 After the article/tooling assembly is sealed in a can, the assembly is then placed in a Hot  
21 Isostatic Press (HIP) and pressurized 409 at a high temperature. As a working example, a  
22 beryllium article is placed in a Hot Isostatic Press and pressurized to over 1900 psi (preferably  
23 2000-2500 psi) at a temperature of over 1650° F (preferably 1700-1750° F) for about three hours.

1 These parameters work well for beryllium. These parameters can be varied substantially  
2 depending on the particular article and depending on apparatus limitations. When the article is to  
3 be formed of a material other than beryllium, the parameters are varied to suit the properties of  
4 the chosen material.

5 **Final Machining**

6 After pressing is completed, the article is removed from the HIP canister and the tooling.  
7 Non-destructive inspection (NDI) and index identification (via X-Ray imaging) are performed  
8 411 to identify the location of any flaws (such as cracks) and of physical features (such as the  
9 interior void). The exterior of the article is then machined 413 using conventional techniques to  
10 give it any desired exterior shape (not shown).

11 HIP vessel bonding according to the method of the present invention is also useful for  
12 bonding metals other than beryllium. Examples of other suitable materials for practice of the  
13 invention are beryllium/aluminum alloy, titanium, stainless steel, and aluminum.

14 The bonding method of the present invention is useful for making thermal control  
15 devices, propulsion systems, cryogenic coolers, heat exchangers, vacuum systems, and other  
16 pressure vessels. Such pressure vessels are useful for scientific detectors and for space flight  
17 applications. A heat exchanger made according to the disclosed method is useful for automotive  
18 applications as a “radiator” heat exchanger. Typically these systems require weight  
19 optimization, high reliability and the ability to withstand large temperature cycling throughout  
20 their functional life.

21 The article to be manufactured may be any shape. The roughly cube shaped article  
22 illustrated in the drawings appended hereto is but an arbitrary example of the various shapes in  
23 which articles may be formed according to the present invention.

1       The present invention has been described in terms of preferred embodiments. However,  
2       numerous modifications and variations may be made to the invention as described without  
3       departing from the scope of the invention.

A copy of the written description of the invention, the claims, and the drawings filed in the U.S. Patent and Trademark Office in connection with the filing of this application is available for inspection at the U.S. Patent and Trademark Office, Washington, D.C. 20591.

WHAT IS CLAIMED IS:

1           1. Method of bonding metal shells to form a vessel having an interior void, the method  
2 comprising:  
3                 forming each of the metal shells with a peripheral flange;  
4                 aligning the metal shells with one another such that their respective peripheral flanges are  
5 engaged with one another;  
6                 assembling the aligned metal shells with tooling to engage the flanges; and  
7                 applying compression force to the flanges, via the tooling, at an elevated temperature so  
8 as to form a diffusion bond joint where the flanges meet.

1           2. The method of bonding recited in claim 1, wherein the region where the flanges  
2 engage one another defines a bond region, and wherein the compression force is applied broadly  
3 across the flanges so as to cover at least the bond region.

1           3. The method of bonding recited in claim 1, wherein the bond joint is formed entirely  
2 over the region where the flanges engage one another.

1           4. The method of bonding recited in claim 1, wherein the metal shells are formed of  
2 beryllium or a beryllium alloy.

1           5. The method of bonding recited in claim 1, wherein the elevated temperature is in the  
2 range of about 1700° F to 1750° F.

1           6. The method of bonding recited in claim 1, wherein the compression force is in the  
2 range of about 2000 psi to 2500 psi.

1           7. A metal bond joint for use with hollow articles formed from metal shells, the bond  
2       joint comprising:  
3           a pair of opposed flanges in contact with one another, each of the opposed flanges being  
4       disposed at the periphery of one of the metal shells, the flanges being aligned with one another  
5       and defining a bond region where they are in contact with one another; and  
6           a diffusion bond between the pair of opposed flanges, formed across the entire bond  
7       region.

1           8. The metal bond joint recited in claim 7, wherein the flanges are shaped such that a  
2       gap, preventing contact of the flanges with one another, is formed in an area between the shells  
3       so as to prevent the bond region from extending into the area between the shells.

1           9. The metal bond joint recited in claim 7, wherein the bond joint is free of filler metal.  
1           10. The metal bond joint recited in claim 7, wherein the metal of the bond joint is  
2       homogeneous.

1           11. The metal bond joint recited in claim 7, wherein the bond joint is formed of  
2       beryllium or a beryllium alloy.

1           12. The metal bond joint recited in claim 7, wherein the diffusion bond is formed by  
2       applying compression force to the flanges at an elevated temperature.

1           13. The metal bond joint recited in claim 12, wherein the elevated temperature is in the  
2       range of about 1700° F to 1750° F.

1           14. The metal bond joint recited in claim 12, wherein the compression force is in the  
2           range of about 2000 psi to 2500 psi.

1           15. A hollow metal article comprising:  
2           a pair of opposed metal shells, and  
3           a metal bond joint, the bond joint comprising:  
4           a pair of opposed flanges in contact with one another, each of the opposed flanges being  
5           disposed at the periphery of one of the metal shells, the flanges being aligned with  
6           one another and defining a bond region where they are in contact with one another;  
7           and  
8           a diffusion bond between the pair of opposed flanges, formed across the entire bond  
9           region.

1           16. The hollow metal article recited in claim 15, wherein the flanges are shaped such that  
2           a gap, preventing contact of the flanges with one another, is formed in an area between the shells  
3           so as to prevent the bond region from extending into the area between the shells.

1           17. The hollow metal article recited in claim 15, wherein the bond joint is free of filler  
2           metal.

1           18. The hollow metal article recited in claim 15, wherein the metal of the bond joint is  
2           homogeneous.

1           19. The hollow metal article recited in claim 15, wherein the bond joint is formed of  
2           beryllium or a beryllium alloy.

1           20. The hollow metal article recited in claim 15, wherein the diffusion bond is formed by  
2 applying compression force to the flanges at an elevated temperature.

1           21. A homogeneous bond joint for use with hollow beryllium articles formed from  
2 beryllium shells, the bond joint comprising:

3           a pair of opposed beryllium flanges in contact with one another, each of the opposed  
4 flanges being disposed at the periphery of one of the beryllium shells, the flanges being aligned  
5 with one another and defining a bond region where they are in contact with one another; and  
6           a diffusion bond between the pair of opposed flanges, formed across the entire bond  
7 region;

8           wherein the flanges are shaped such that a gap, preventing contact of the flanges with one  
9 another, is formed in an area between the shells so as to prevent the bond region from extending  
10 into the area between the shells;

11          wherein the diffusion bond is formed by applying compression force to the flanges at an  
12 elevated temperature.

## ABSTRACT OF THE DISCLOSURE

1           A bond joint and process of bonding metal parts to one another to form seamless, hollow  
2       metal articles, particularly made from beryllium. Tooling is assembled to the parts, prior to hot  
3       pressing, to cause pressure to be applied to flanges that extend peripherally from the parts. The  
4       parts, assembled together with the tooling, are then subjected to hot isostatic pressing of the  
5       flanges at a temperature of about 1700° F to 1750° F, and at a pressure of about 2000 psi to 2500  
6       psi, for around 3 hours. The tooling surrounding the metal parts functions to limit the amount of  
7       compression of the flanges. Articles formed by this process are particularly useful in space flight  
8       applications because they are formed of a homogeneous material. This means that the articles  
9       can operate under high pressure despite being subjected to temperature cycling. Strength of the  
10      bond joint is enhanced because no filler metal is used. The absence of a filler metal also  
11      eliminates any thermal stress problems as a result of differences in coefficients of thermal  
12      expansion.

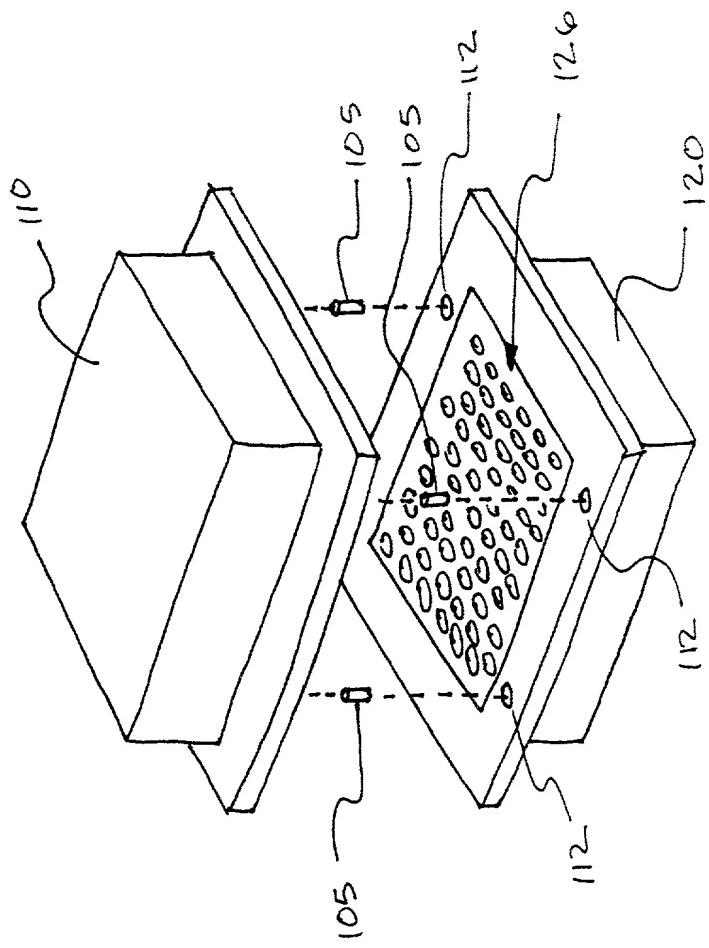
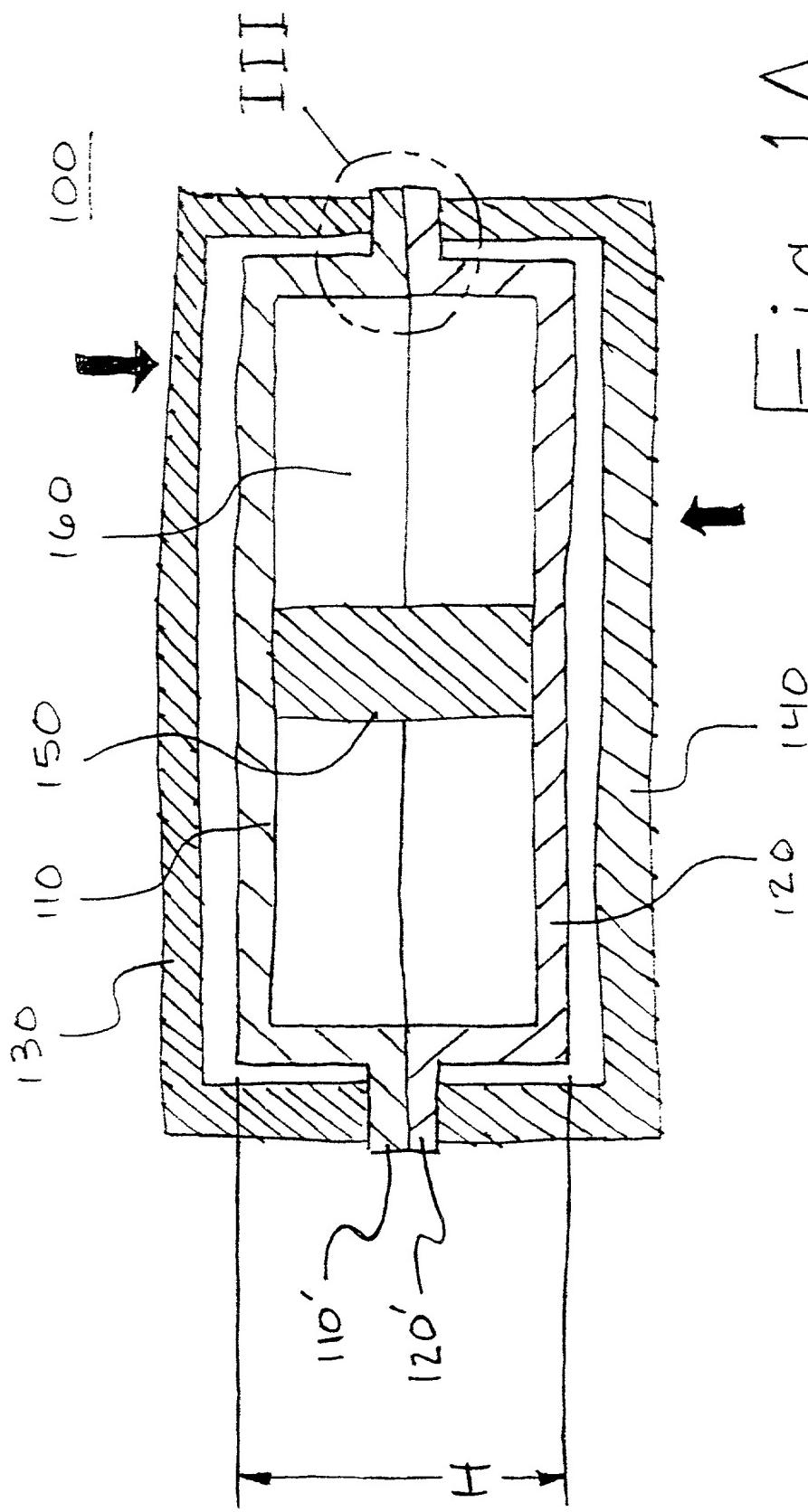


Fig. 1

Fig. 1A



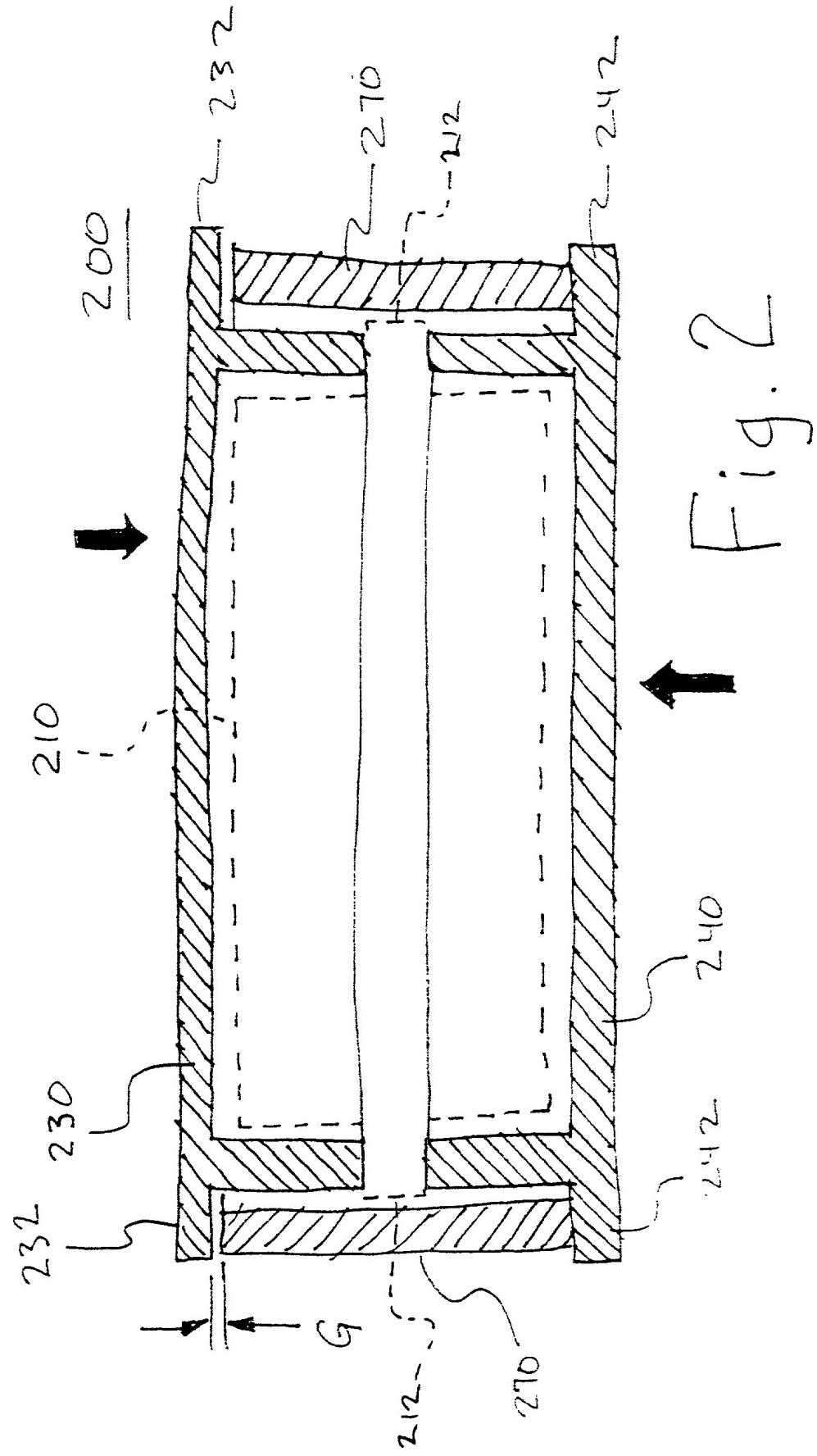
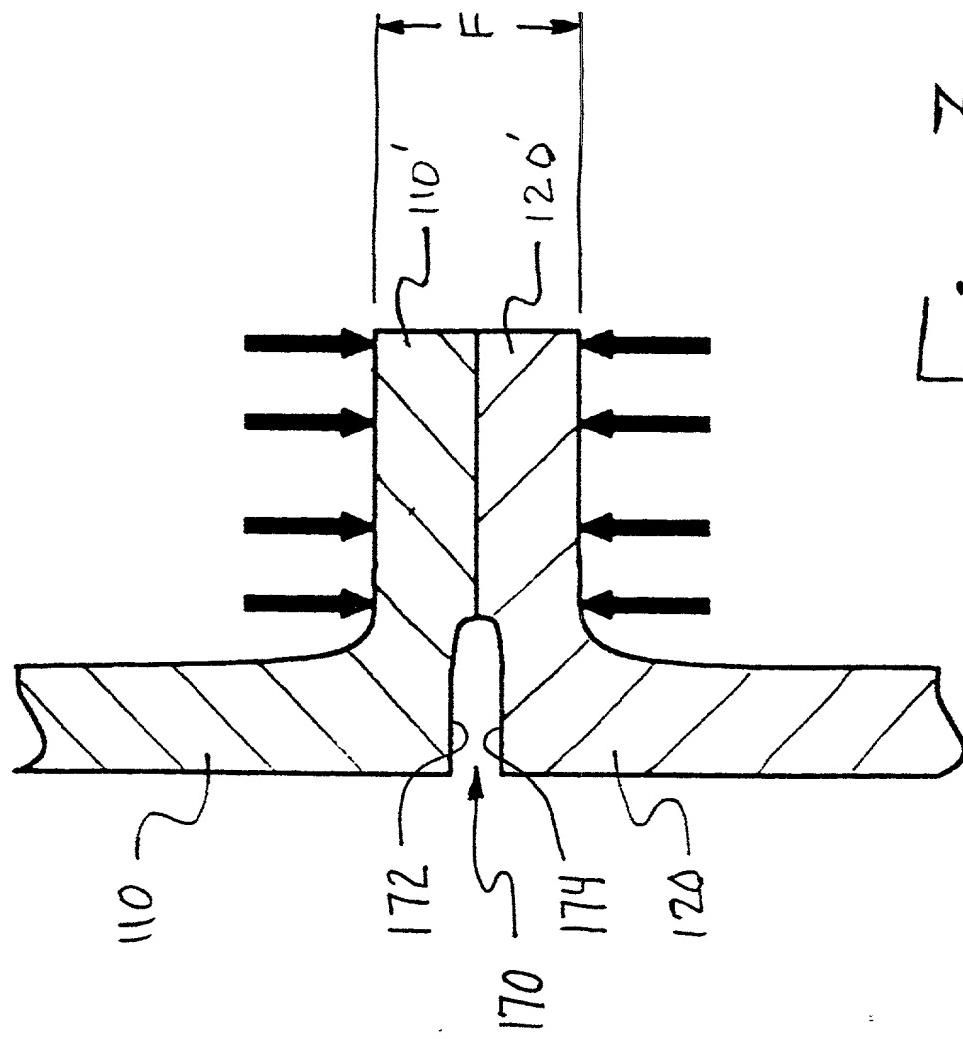


Fig. 3



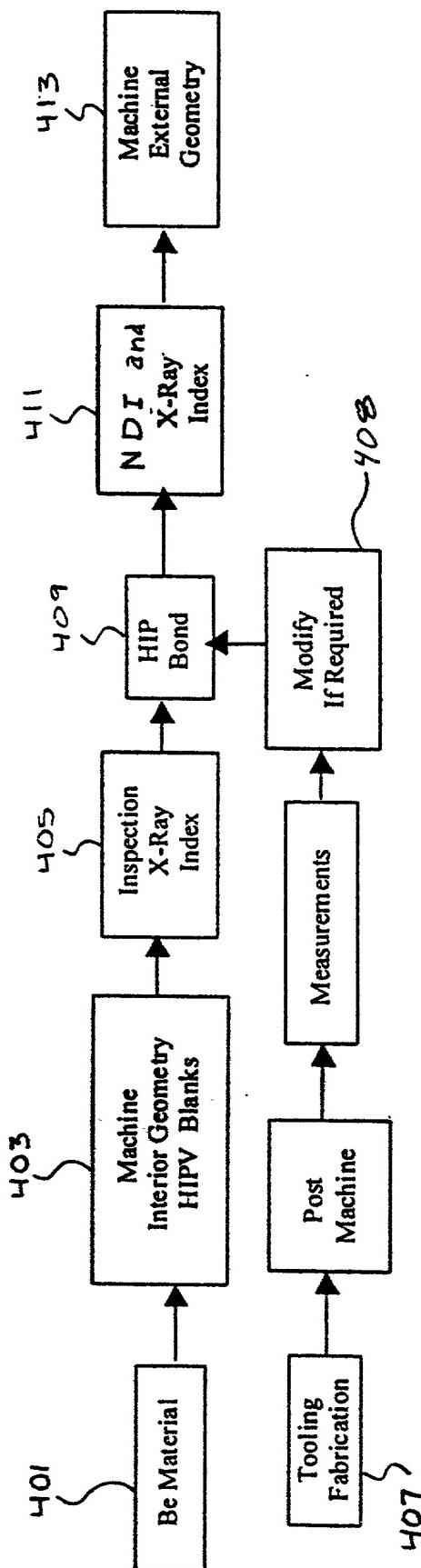
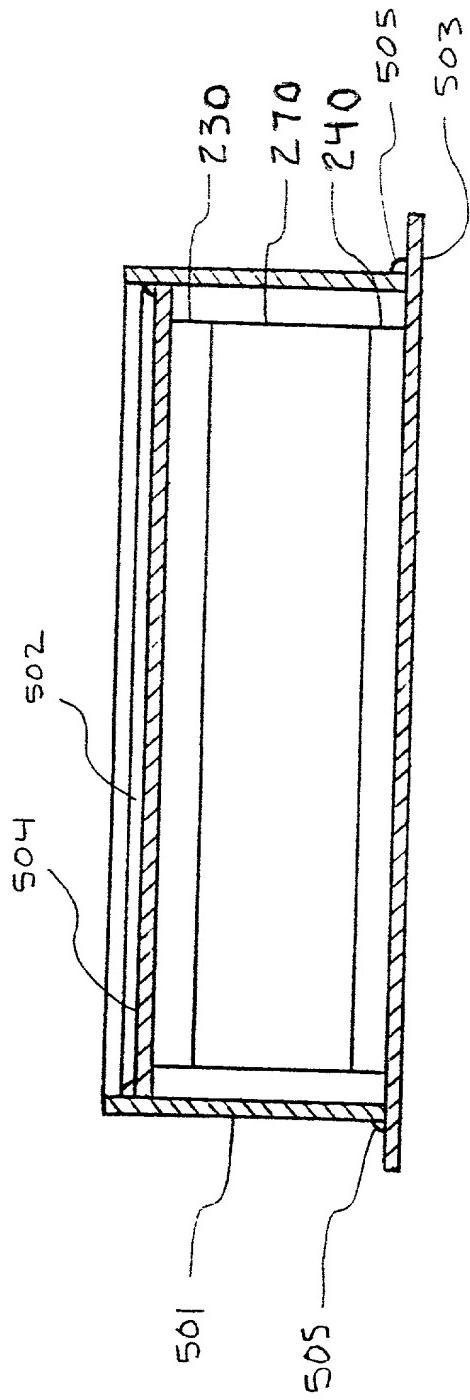


Fig. 4

E. 9. 5



**IN THE UNITED STATES PATENT AND TRADEMARK OFFICE**

In re Application of Charles J. Stouffer and David C. Bugby

Serial No.: Not yet assigned                                  Group Art Unit:

Filed: Herewith    Examiner:

For:    **HIGH TEMPERATURE ISOSTATIC PRESSURE BONDING OF HOLLOW BERYLLIUM PRESSURE VESSELS USING A BONDING FLANGE**

**DECLARATION AND POWER OF ATTORNEY FOR PATENT APPLICATION**

As below inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, joint and first inventor of the subject matter which is claimed and for which a patent is sought on the invention entitled **HIGH TEMPERATURE ISOSTATIC PRESSURE BONDING OF HOLLOW BERYLLIUM PRESSURE VESSELS USING A BONDING FLANGE**, the specification of which is attached hereto.

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, § 1.56(a).

I hereby appoint the following attorney(s) to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith:

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I declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements are made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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